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6. AUTHOR(S)
Stephen M. Robinson

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University of Wisconsin-Madison
Department of Industrial Engineering
1513 University Avenue
Madison, WI 53706-1572

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13. ABSTRACT *(Maximum 200 words)*

The primary aim of this work was to enhance the method of scenario analysis for decision-making under uncertainty. An effect of such enhancement could be to help the Army make better decisions in situations involving resource allocation under uncertainty, particularly those involving force and weapon mix issues.

Scenario analysis models employ a finite probability distribution describing different *scenarios* (that is, possible states of the decision environment), and they then compute solutions that optimize against these scenarios according to some appropriate decision criterion. For example, one might seek a decision that provided maximum expected performance on some measure of effectiveness, subject to various operational constraints (which can be different in different scenarios), or one might look for a decision providing minimum variance in performance across scenarios, subject to a floor on expected performance.

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Various supporting studies were also carried on to improve the underlying optimization methodology that supports the scenario analysis paradigm. These included work in stochastic optimization and in nonsmooth optimization, as well as in Bayesian analysis for estimating value in military system testing.

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Final Report

Stephen M. Robinson

November 1993

U.S. Army Research Office

Grant No. DAAL03-92-G-0408

University of Wisconsin–Madison

1. Problem studied

The primary aim of this work was to enhance the method of scenario analysis for decision-making under uncertainty. An effect of such enhancement could be to help the Army make better decisions in situations involving resource allocation under uncertainty, particularly those involving force and weapon mix issues.

Scenario analysis models employ a finite probability distribution describing different *scenarios* (that is, possible states of the decision environment), and they then compute solutions that optimize against these scenarios according to some appropriate decision criterion. For example, one might seek a decision that provided maximum expected performance on some measure of effectiveness, subject to various operational constraints (which can be different in different scenarios), or one might look for a decision providing minimum variance in performance across scenarios, subject to a floor on expected performance.

Various supporting studies were also carried on to improve the underlying optimization methodology that supports the scenario analysis paradigm. These included work in stochastic optimization and in nonsmooth optimization, as well as in Bayesian analysis for estimating value in military system testing.

2. Principal results achieved

In work under this grant we achieved results in several areas. A long paper was prepared and submitted for publication, describing a computational method for solving large scenario analysis problems. This paper, written jointly with B. J. Chun, is listed in Section 3.

We also conducted extensive mathematical and computational studies of Markov and semi-Markov models of campaign analysis: that is, scenario analysis in which some scenarios involve repetitive events (such as battles fought in succession, with or without resupply operations intervening). This work is still in process, and it may eventually result in one or more technical papers for journal publication.

We also conducted supporting research in areas that advance optimization methodology supporting the scenario analysis paradigm. One of these studies applied Bayesian prior-to-posterior analysis to estimate the expected value of testing a weapon system under development. This methodology could be used to help decide whether live fire testing, as mandated by Congress, is unreasonably expensive and impractical (so that, under the law, a waiver may be granted). This work is described in the paper, "Estimating expected value of system testing," listed in Section 3.

A second area of study involved optimization of stochastic systems whose performance can be evaluated by simulation. This work was applied particularly to problems in manufacturing (tandem production lines) and in project scheduling (stochastic PERT networks). Three papers resulting from these investigations are reported in Section 3.

In other work supported in part by this grant, we investigated so-called normal maps, which are devices for converting variational inequalities into single-valued, although generally nonsmooth, equations. Zeros of the equations correspond one-to-one with solutions of the variational problems. Further, many of the methods of the differential calculus can be carried over to these problems *even though the functions involved are nonsmooth,* if the methods are suitably adapted. We showed how the well known Newton method could be extended to the problem of finding zeros of such functions, and described this application in a paper reported in Section 3.

It is perhaps appropriate to mention here that during the period of this grant the Army's 1992 Wilbur Payne Memorial Award for the best individual analysis of that year was presented to Mr. Richard R. Laferriere of the TRADOC Analysis Command, for his paper, "Scenario analysis for combat systems." In portions of his work Mr. Laferriere employed methodology developed during earlier phases of this research program (under a predecessor ARO contract, DAAL03-89-K-0149).

3. Publications and technical reports

The following papers acknowledge support from Grant DAAL03-92-G-0408:

B. J. Chun and S. M. Robinson, "Scenario analysis via bundle decomposition," submitted to *Annals of Operations Research.*

S. M. Robinson, "Convergence of subdifferentials under strong stochastic convexity," submitted to *Management Science.*

E. L. Plambeck, B.-R. Fu, S. M. Robinson, and R. Suri, "Throughput optimization in tandem production lines via nonsmooth programming," *Proceedings of 1993 Summer Computer Simulation Conference,* Society for Computer Simulation, San Diego, CA 1993, pp. 70–75.

E. L. Plambeck, B.-R. Fu, S. M. Robinson, and R. Suri, "Optimizing performance functions in stochastic systems," submitted to *Mathematical Programming.*

S. M. Robinson, "Estimating expected value of system testing," to appear in *Evaluation Strategies for Live Fire Planning, Analysis and Testing,* by Dr. Paul H. Deitz *et al.*, Report, AMSRL-SL-B, U. S. Army Research Laboratory (Survivability/Lethality Analysis Directorate, Ballistic Vulnerability/Lethality Division), to be issued approximately 31 Jan 1994.

S. M. Robinson, "Newton's method for a class of nonsmooth functions," accepted by *Set-Valued Analysis.*

4. Participating scientific personnel

The following scientific personnel participated in the work under Grant DAAL03-92-G-0408 during part or all of its duration.

Stephen M. Robinson, Professor.

Ju-Long Chen, Research Assistant.

Sheng-Yuan Shen, Research Assistant (Mr. Shen qualified during his work on this project for the degree of Master of Science – Industrial Engineering. The degree is to be awarded in December 1993).

5. Reportable inventions

To the best of the principal investigator's knowledge, there were no reportable inventions during the course of this research.